Exploring the DET vs MPPT Trade for CubeSat to ESPA Sized Earth-Orbiting Spacecraft

Space Dynamics Laboratory
Utah State University

Aaron P. Aboaf*, Jerome D. Hittle‡
*Space Dynamics Laboratory, Logan, Utah | ‡AmplifiedSpace, Longmont, Colorado

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Previous research has evaluated different EPS topologies from efficiency, reliability, and cost perspectives[1, 2, 3], but has yet to incorporate orbital dynamics and mission attitude constraints into the overall evaluation of the most effective EPS topology for a specific mission's needs. For efficient system architecture design, systems engineers must quickly assess the orbit-average maximum load that can be accommodated based on the orbit, pointing constraints, solar array collection area, and EPS efficiency to determine operational feasibility. The authors present preliminary findings showing that attitude constraints and the inclination/β-angle have significant effects on the available energy the spacecraft can capture and the size of the load the spacecraft can support.

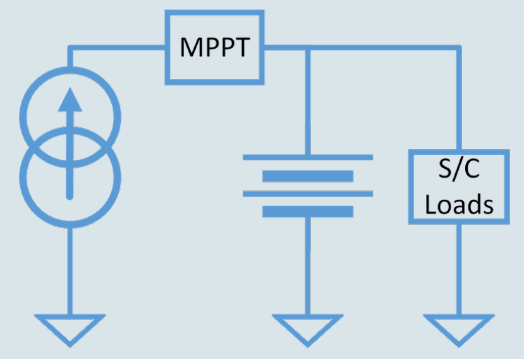
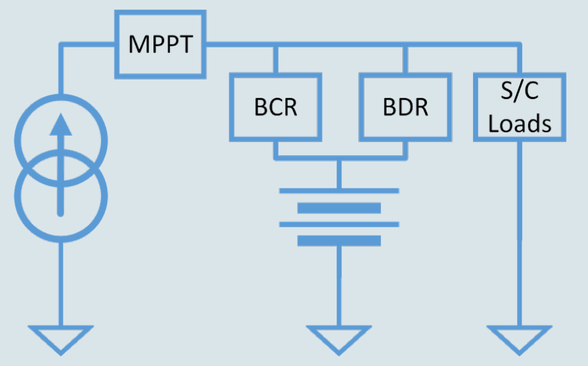
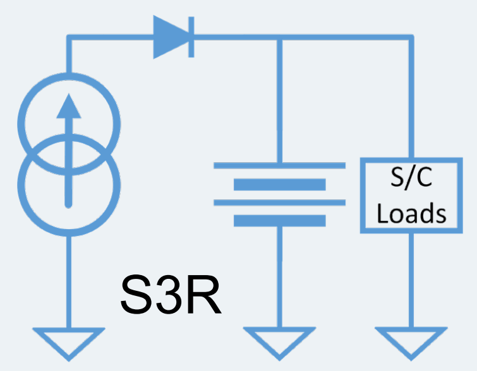
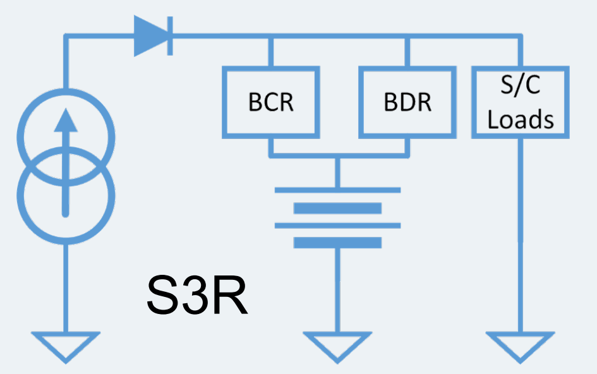
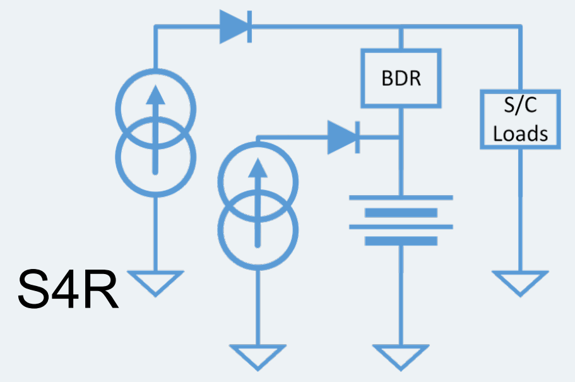
Background

- Orbital dynamics and mission constraints determine the energy available to the spacecraft
- This research brings orbital dynamics and broad mission constraints together with the previous research to answer common design questions based on the specific mission
  - Is the solar array sized appropriately for the payloads?
  - Is the spacecraft power positive?
  - How does a larger solar array affect SWaP-C metrics?
  - What is the best suited EPS architecture for the mission?
- Assumptions:
  - Orbit data analyzed for the worst-case sun conditions independent of orbital precession

Power Architectures

- Considered five basic EPS architectures (see Table 1)
  - Other hybrid topologies exist
  - It's important to understand the efficiency of the chosen architecture – as it has direct impact on solar array sizing and/or power available
- MPPT – Constant conversion loss in an expensive and complicated topology. A lot of use in smallsats due to high efficiency needs
- DET – Minimal power loss at the piece-part level, but significant losses can result due to purposely operating below the maximum power of the solar array. Cheap and easy to implement in the unregulated case (continuing to make it a very popular option), moderate complexity in the regulated case, but competitive efficiency to MPPT

Table 1. EPS Topologies Considered

	Unregulated	Regulated
MPPT		
DET		 

Analysis Methodology

- Gather data using a Systems Tool Kit simulation
  - Analyze over inclination, altitude, and the β angle which itself a function of inclination and angle of right ascension (RAAN, Ω)
  - Simulate identical orbits for sun, nadir, and velocity primary pointing constraints (secondary pointing constraint is towards sun)
  - Measure the solar fluence, eclipse periods, and angle between solar array normal vector and sun vector
- Define the solar efficacy metric, K
  - A measure of how often the solar array is illuminated during an orbit.
  - The total energy available during the orbit (E_{avail}) is normalized to the maximum energy that could be received by the spacecraft if the spacecraft were normal to the sun and illuminated during the entire orbit (E_{max}).

$$K = \frac{E_{avail}}{E_{max}} = \frac{H_e(r_0, \beta)}{C \cdot T}$$

- The maximum orbit-average load power can be defined as follows:

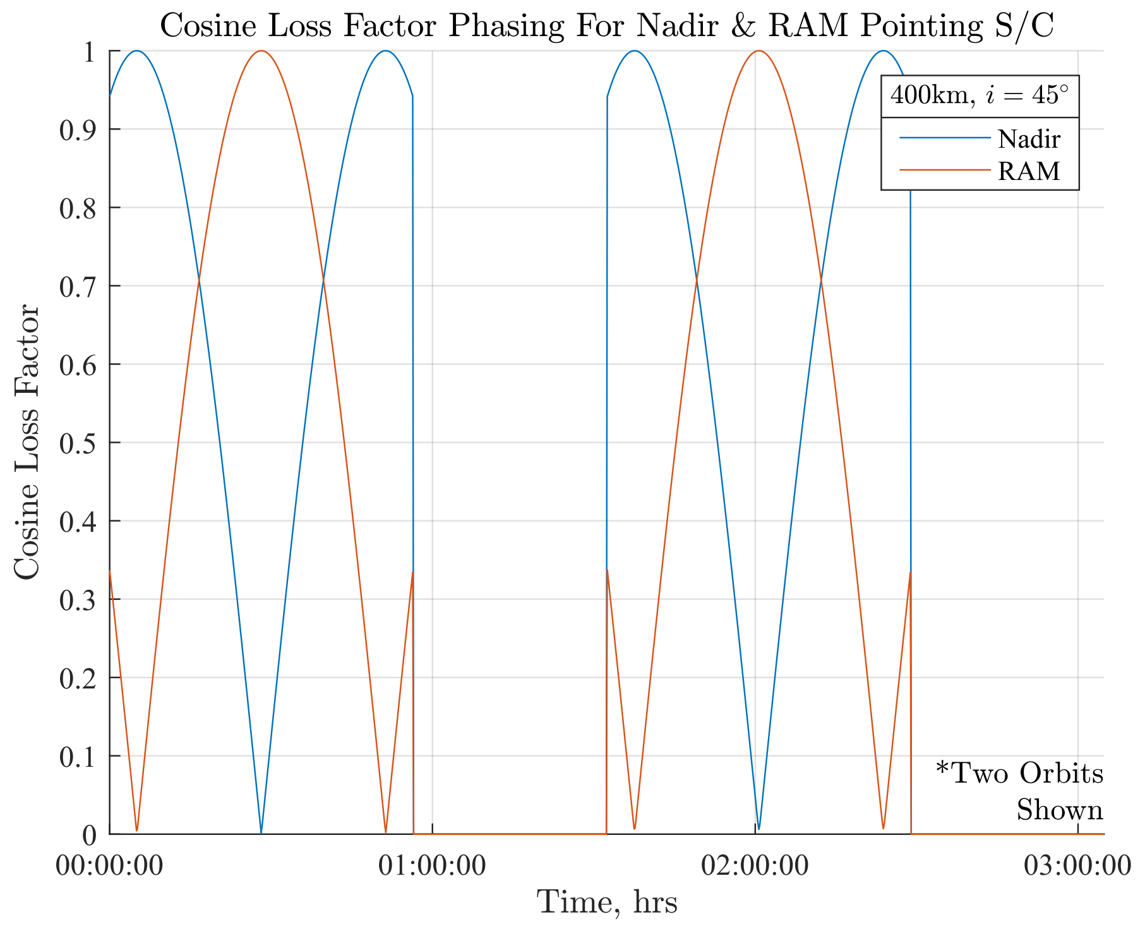
$$P_{load,max} = \eta_{EPS} \cdot \eta_{SA} \cdot H_e(r_0, \beta) \cdot A/T$$

- Rewriting using the previously defined solar efficacy provides a simple equation to quickly determine power generation of a given spacecraft.

$$P_{load,max} = \eta_{EPS} \cdot \eta_{SA} \cdot K \cdot C \cdot A$$

Table 2. Variable Definitions

Variable	Definition
C	Solar Constant, 1321 W/m^2
T	Orbit Period, s
A	Solar Array Area, m^2
H_e	Available Solar Fluence During One Orbit, J/m^2
K	Solar Efficacy
β	Orbit Beta Angle, °
r_0	Semi-major Axis, m
η_{SA}	Solar Array Efficiency
η_{EPS}	EPS Efficiency



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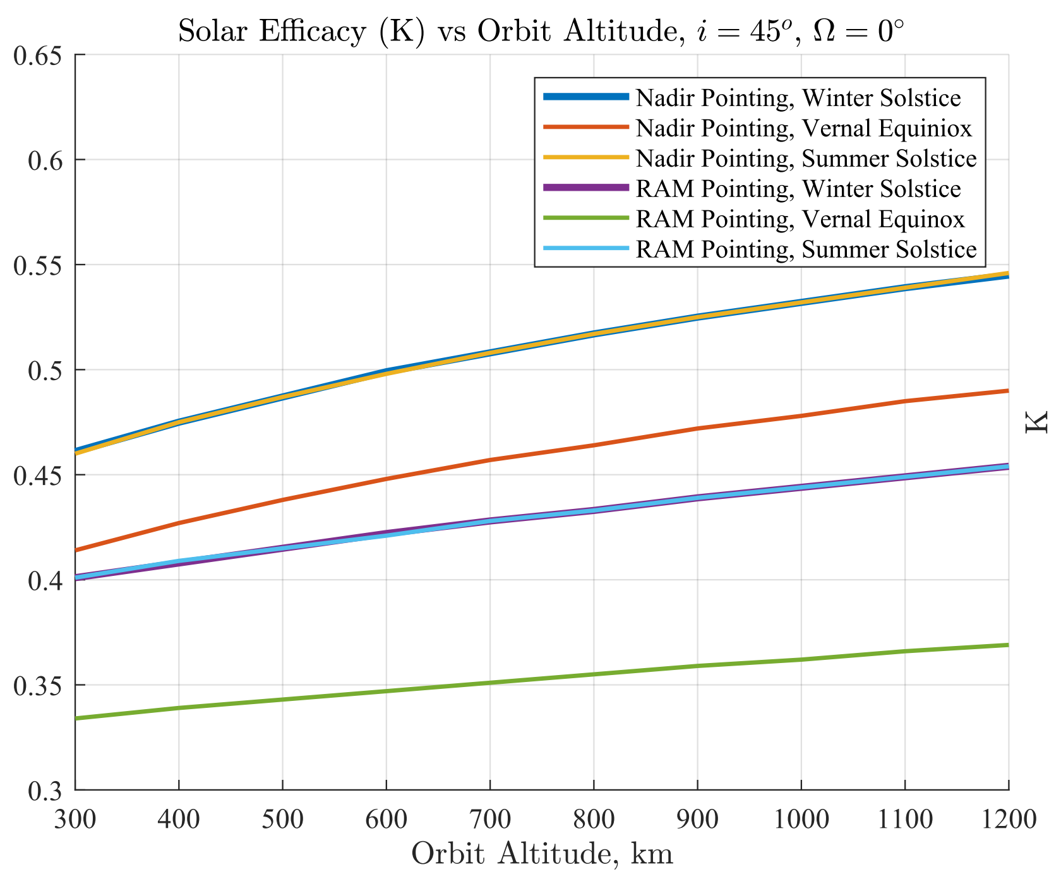
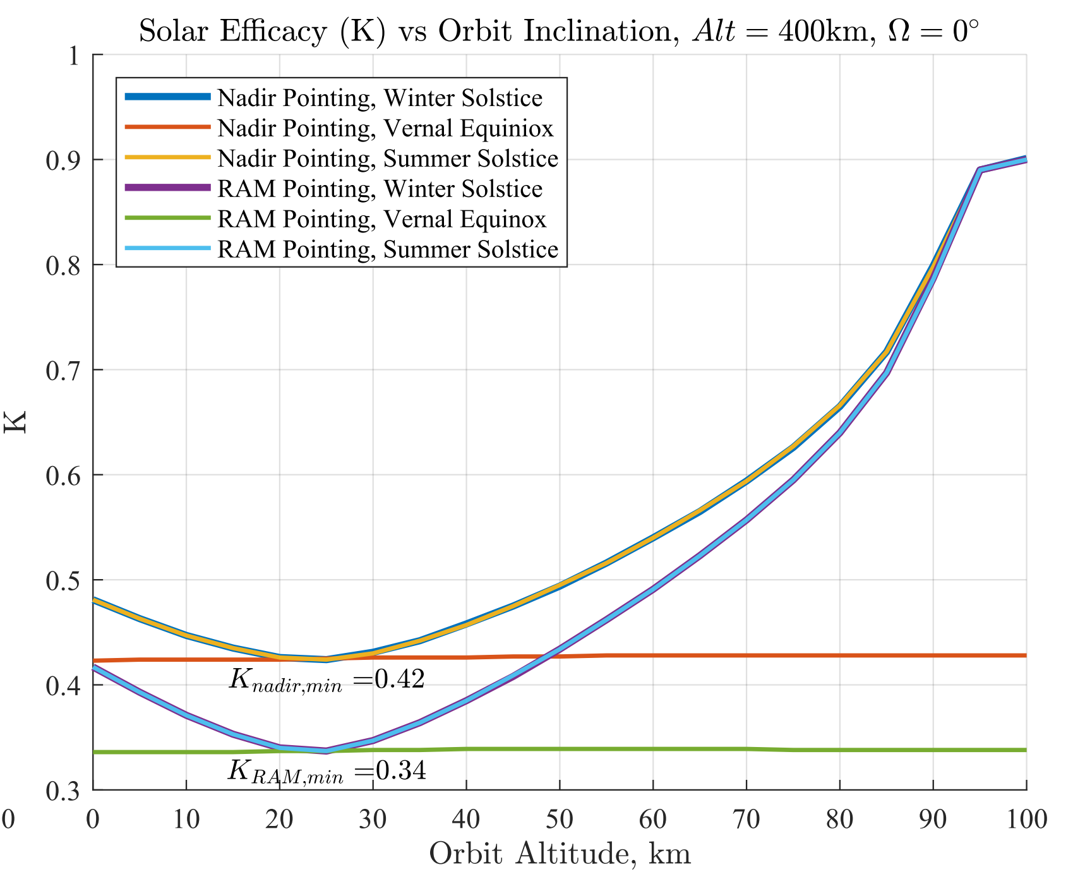
Case Study Preliminary Results

- The worst-case solar efficacy for any given orbit is approximately constant due to unknown orbit precession at the equinox





<u>Requirements</u>: 3U spacecraft, ISS orbit (420km, 51.6º), 9.5W orbit-average load, RAM pointing, 10cm x 30cm solar panel (210 cm^2, 25.5% efficient at 85C, BOL)

<u>Analysis</u>: None of the 3 panel solutions are feasible and the spacecraft must accommodate 5 panels, either by utilizing hinges or increasing the spacecraft size to 6U. US3R is not feasible. While MPPT, RS3R, and RS4R are all feasible with 5 panels, other studies have shown that RS4R is rated the highest when considering cost, efficiency, and reliability[2].

Table 3. Case Study Results

		$P_{load,max}$	
EPS	η_{EPS}	3 panel	5 panel
UMPPT	0.9	6.46W	10.75W
RMPPT	0.85	6.09W	10.16W
US3R	0.7	5.02W	8.37W
RS3R	0.82	5.88W	9.80W
RS4R	0.8	5.73W	9.56W

Next Steps

- Explore if an equation can be formulated to predict solar efficacy
- Compile a whitepaper providing more details on this research
- Understand how system level SWaP-C is affected
- The authors request feedback (both positive and constructive) from other experts in the field. <u>If you've taken the time to look at this poster, please provide feedback to the authors, as it will help improve the final paper.</u>

-Contact Us-

We'd like to hear your insight!

Aaron P. Aboaf
Space Dynamics Laboratory
Spacecraft Systems Engineer
aaron.aboaf@sdl.usu.edu

Jerome D. Hittle
AmplifiedSpace
Founder & CEO
jhittle@amplifiedspace.com

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